University of Twente
The Netherlands

MESA+
Institute for Nanotechnology

Department of Science and Technology

Laser Physics and Non-Linear Optics Group

Modelling mirror aberrations in FEL oscillators using OPC

Peter van der Slot

Jaap Karssenberg *Klaus Boller*

Content

- Introduction
- Zernike Polynomials & Phase aberrations
- Case : 4GLS VUV-FEL oscillator
- Conclusions

University of Twente
The Netherlands

High Average Power FELs

- Operational
  - JLab, ERL FEL oscillator, infrared > 10 KW
  - JAERI, ERL FEL oscillator, infrared 10 kW class
  - Budker INP, ERL, NovoFEL, oscillator, THz 1 kW class
- Design
  - 4GLS, ERL FEL oscillator, VUV > 300 W (@ 4⅓ MHz)

- High average power
  - Radiation extraction
  - Mirror distortion due to thermal loading
- OPC
  - Optical propagation in paraxial approximation
  - Genesis 1.3 or Medusa for gain section
  - Phase masks
    - Build-in Zernike polynomials
    - User supplied external file

Phase change and Zernike polynomials

$$d\theta(r) = A'_{nm} R_n^{|m|}(\rho) \times \begin{cases} \cos(m\varphi) & m \geq 0 \\ \sin(m\varphi) & m < 0 \end{cases}$$

$$\rho = \frac{r}{\rho_c} = \frac{\sqrt{x^2 + y^2}}{\rho_c}, \quad \varphi = \tan^{-1}(\frac{y}{x})$$

n	m	Type
4	0	Spherical aberration
3	1	Coma
2	2	Astigmatism

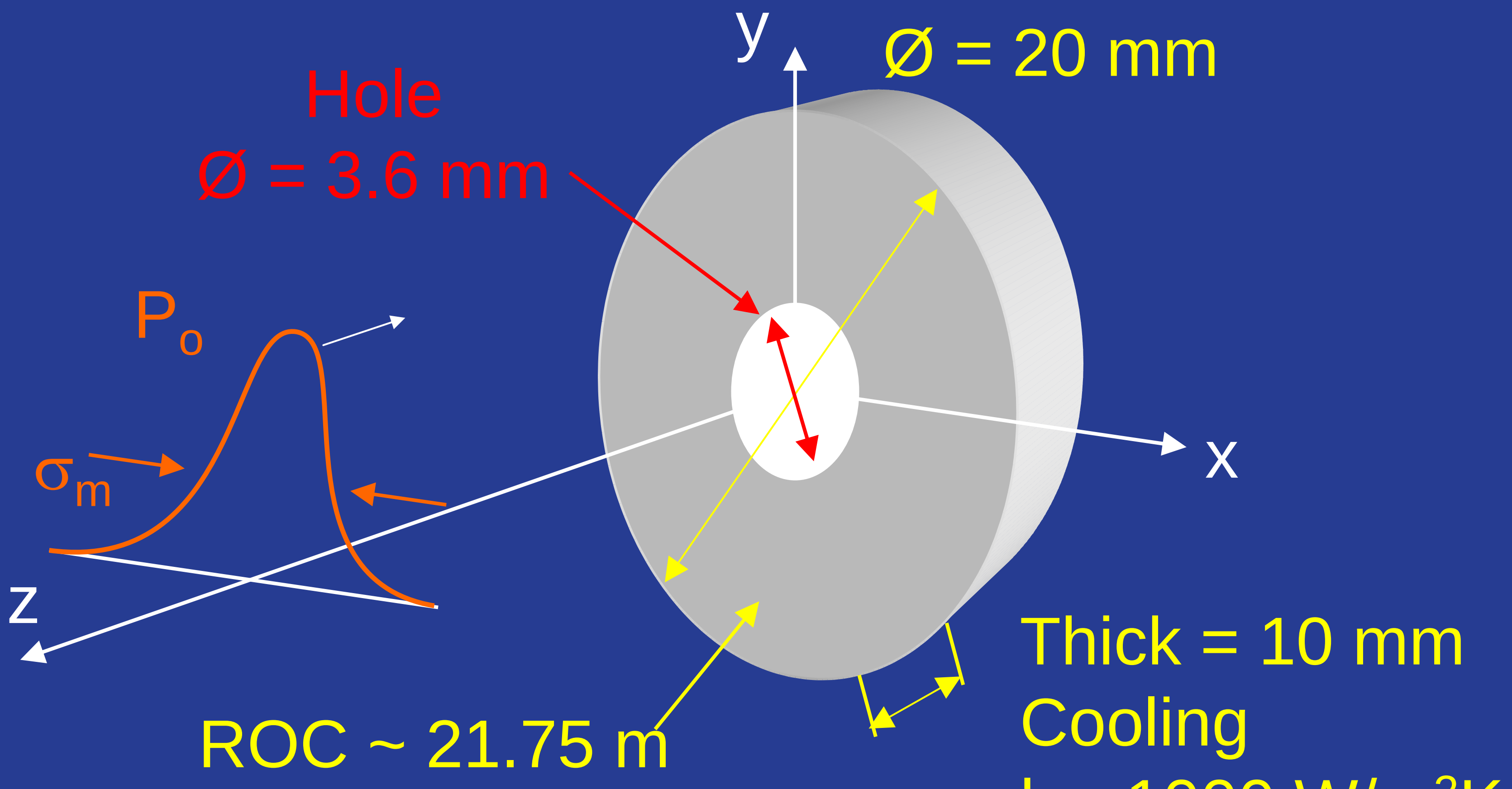
University of Twente
The Netherlands

4GLS VUV FEL oscillator

- ERL, 80 pC, I_p = 300 A, n $\times$ 4⅓ MHz
- Undulator, 3 modules, λ_u=58 mm, N_u=52
- E_b = 549.3 MeV, K=1.98 $\Rightarrow$ λ = 123.9 nm
- Cavity

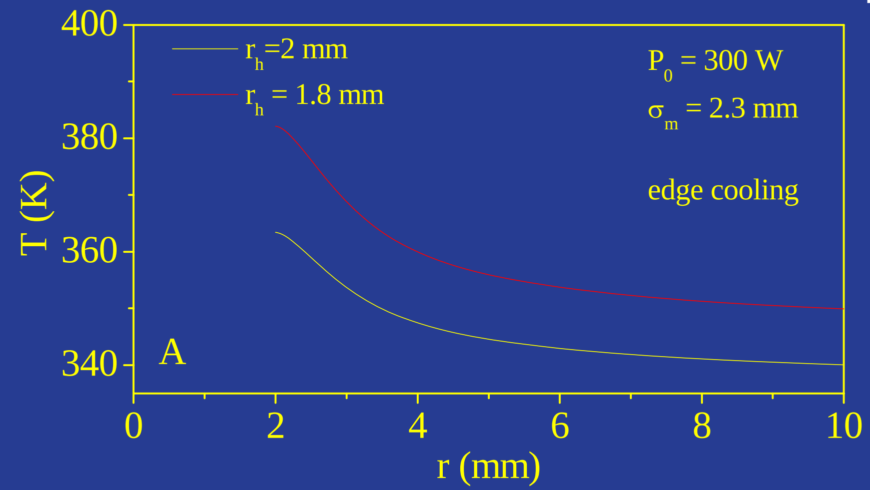
– Length	34.6 m	$g_1 g_2$	0.82
– US ROC	14.5 m	R	60 %
– DS ROC	21.75 m	w_0	0.38 mm
– Hole r_h	1.8 mm		

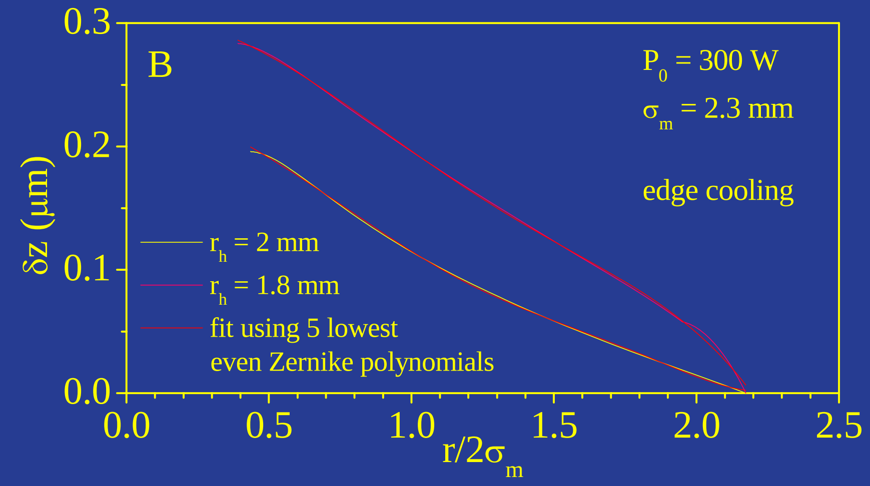
Thermal distortion – DS mirror



University of Twente
The Netherlands

Surface displacement





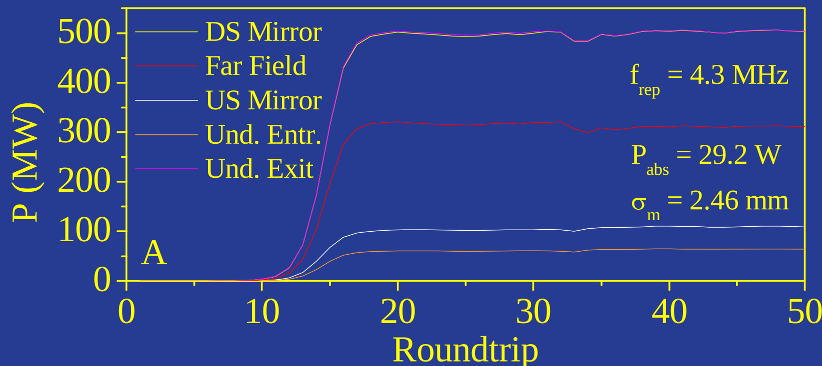
$$\delta z\left(\frac{r}{2\sigma_m}\right) = \sum_{n\ even} A_{n0} R_n^0\left(\frac{r}{2\sigma_m}\right)$$

$$d\theta = -\frac{4\pi\delta z}{\lambda}$$

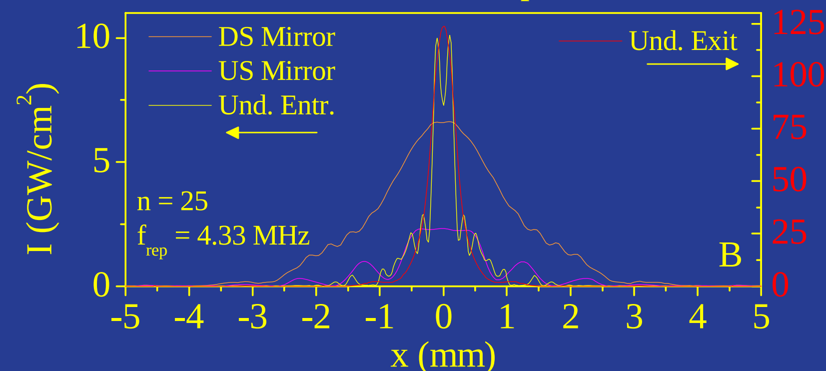
Fit used n=0, 2,…, 8

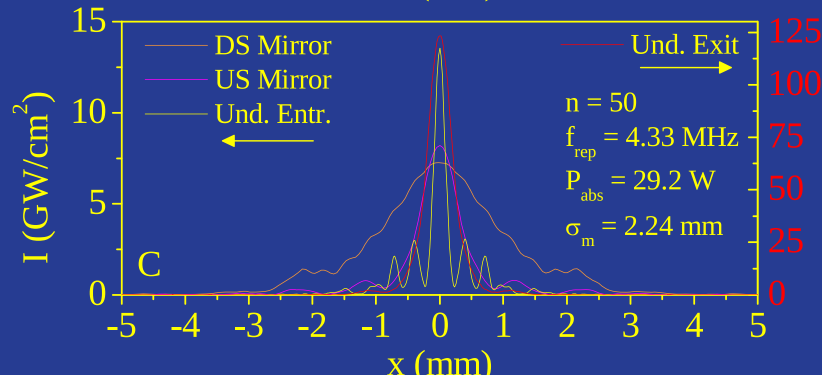
Difference << λ/10

University of Twente
The Netherlands

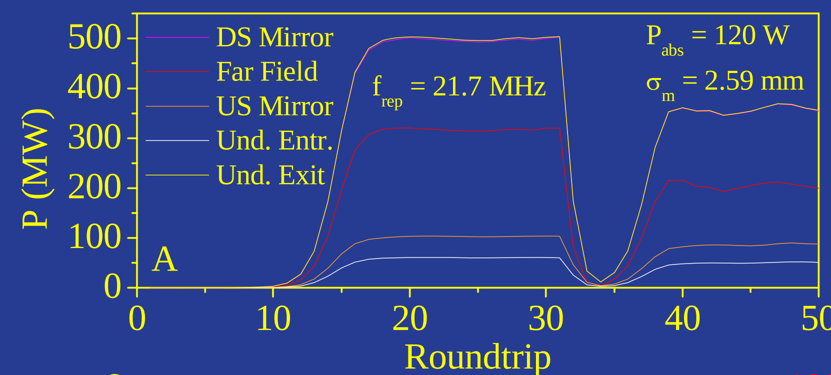


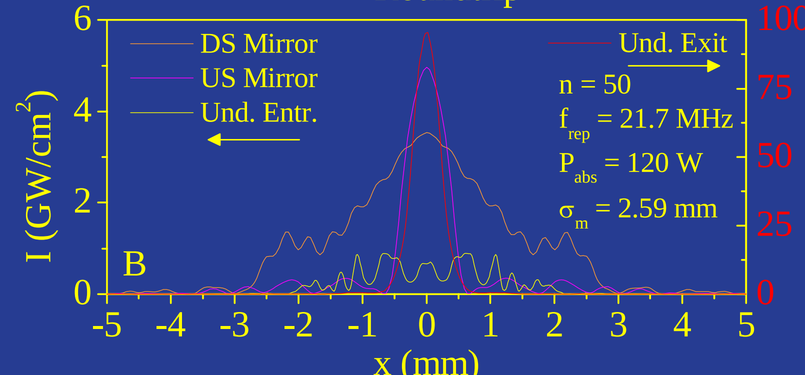
f_{rep} = 4⅓ MHz





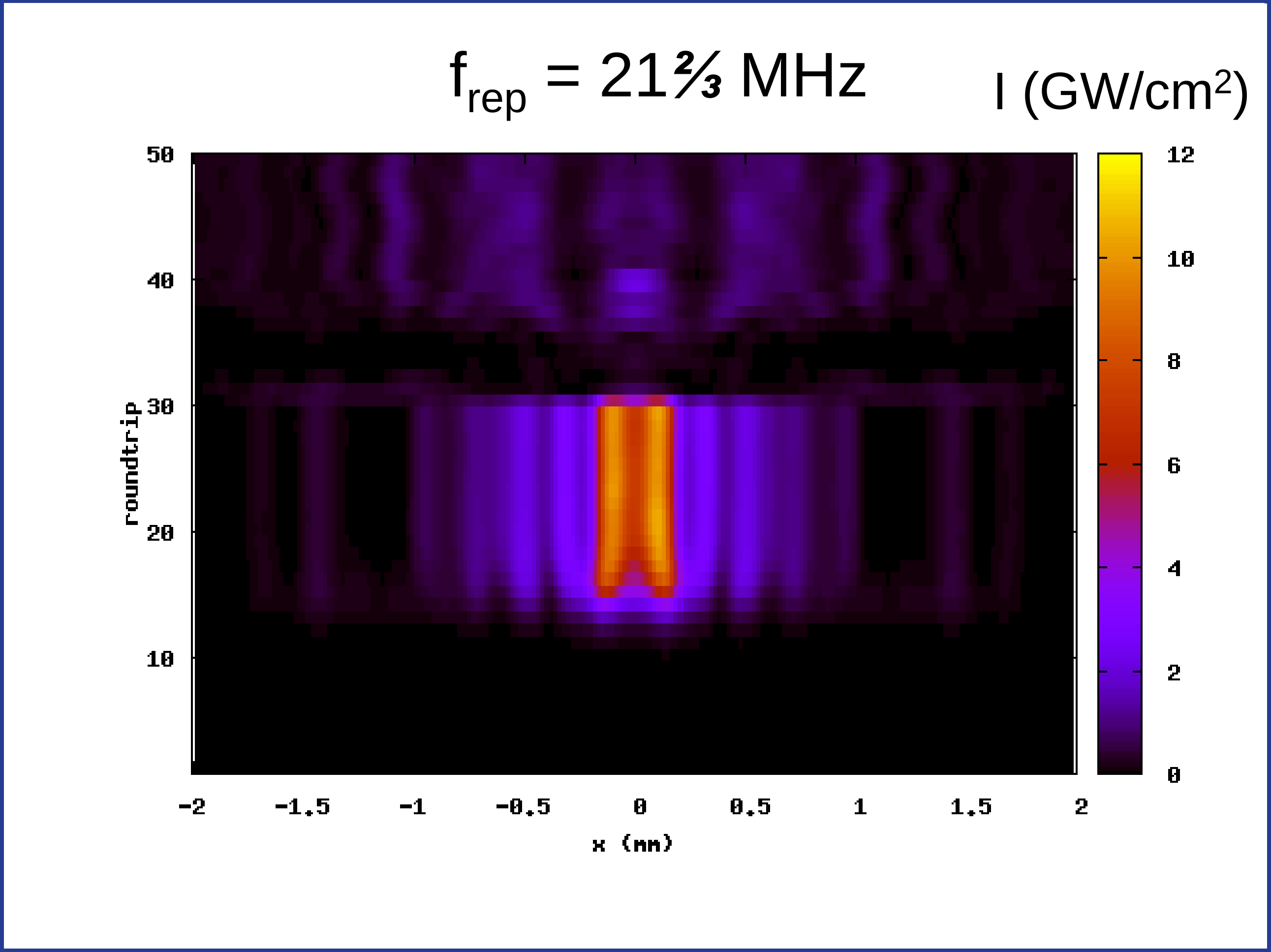
f_{rep} = 21⅔ MHz



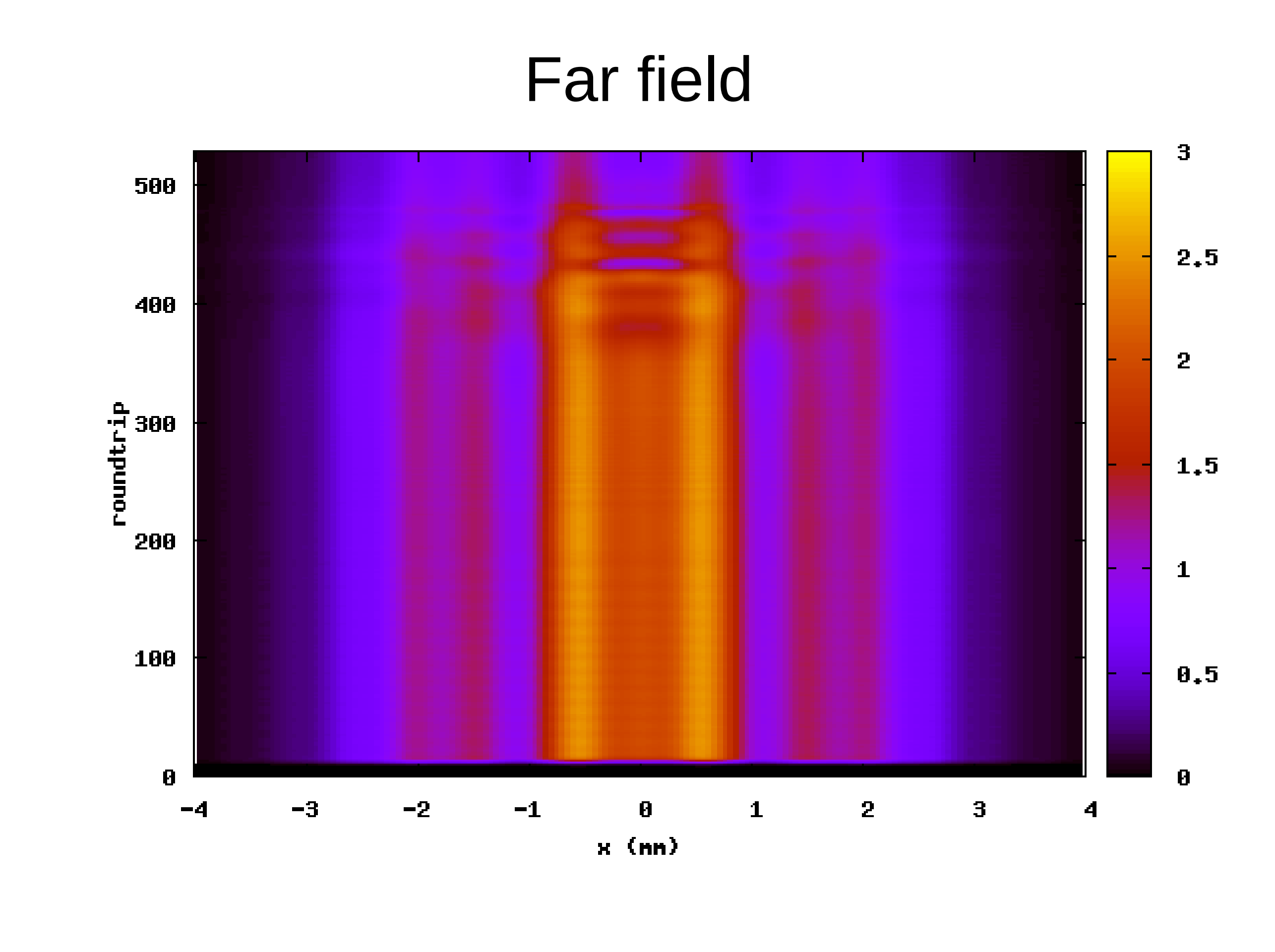


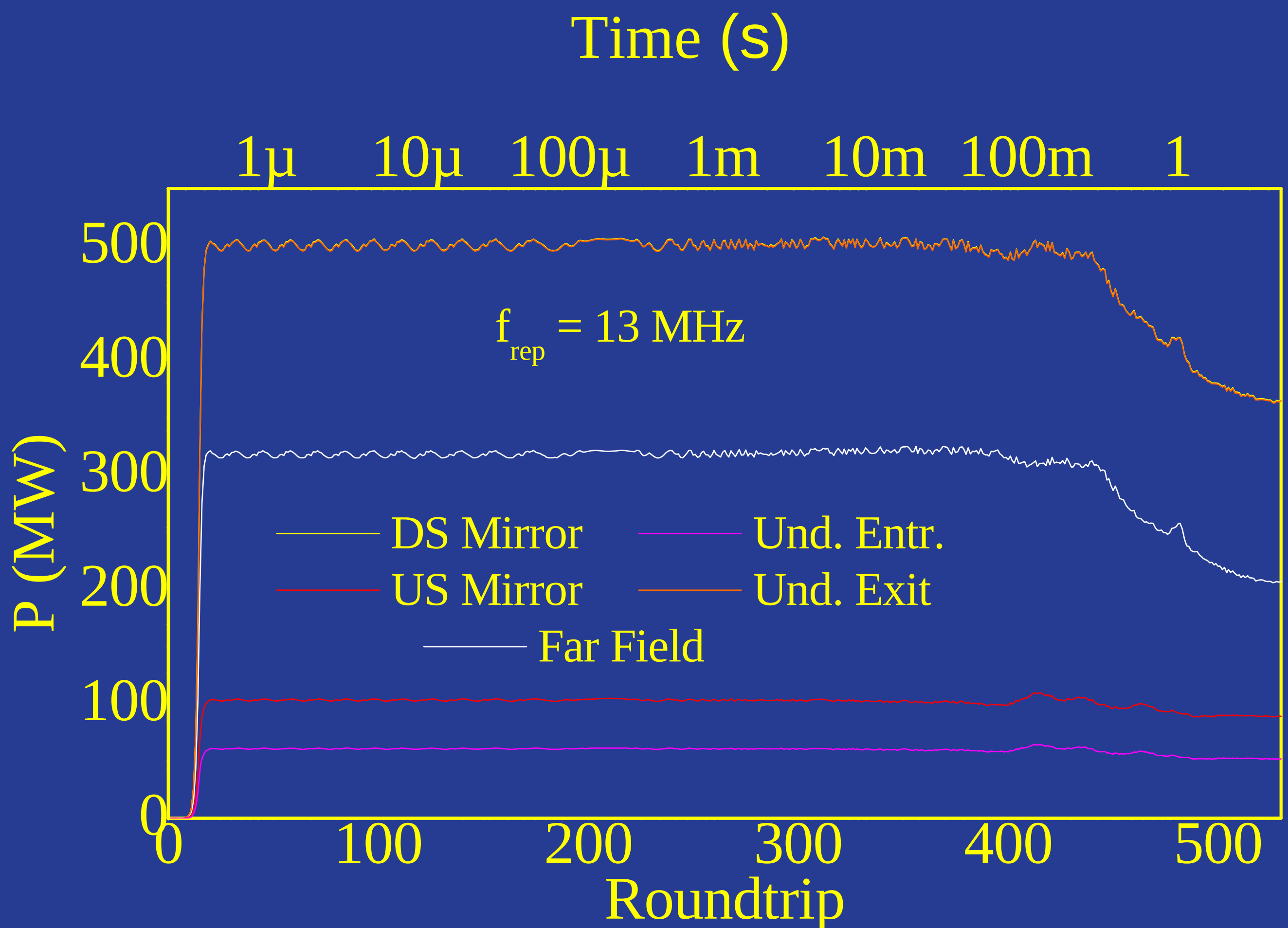
University of Twente
The Netherlands

Cross section undulator's entrance



Gradual thermal distortions




Time (s)
1µ 10µ 100µ 1m 10m 100m 1
500
400
300
200
100
0
P (MW)
f_{rep} = 13 MHz
DS Mirror
US Mirror
Und. Entr.
Und. Exit
Far Field
0 100 200 300 400 500
Roundtrip

University of Twente
The Netherlands

Summary

- OPC can model arbitrary mirror aberrations
  - Build in Zernike polynomials
  - External supplied Phase Mask
- OPC can interface with external programs
- Used to model thermal distortions

Summary 4GLS VUV-oscillator

- Hole coupled output mirror
  - Finite element program gives surface displacement for Gaussian load
  - OPC generates Phase Mask using build in Zernike polynomials
- Applying full mirror distortion instantaneous after oscillator saturates:
  - Oscillator is quite resilient
  - Average powers in excess of 1 kW can be expected

Summary 4GLS VUV FEL oscillator

- Gradually applied mirror distortions (13 MHz)
  - Power starts to drop after several hundred milliseconds
  - After 4 seconds close to steady state
  - More work is required
- Comparison between Medusa and Genesis 1.3
  - Some difference in start-up phase
  - Just started using Medusa in combination with thermal distortions